Long Range Transport of Asian Pollutants to the Northern Sacramento Valley during CalNex

A. O. Langford[1], C. J. Senff[1,2], R. J. Alvarez II[1], R. M. Hardesty[1], A. M. Weickmann[1,2], R. M. Banta[1], R. D. Marchbanks[1,2], S. P. Sandberg[1], W. A. Brewer[1], J. Brioude[1,2]

[1]NOAA Earth System Research Laboratory, Boulder, CO
[2]CIRES, University of Colorado, Boulder, CO
Email: andrew.o.langford@noaa.gov

Introduction

Ozone (O_3) formed through photochemical reactions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) from anthropogenic sources is a serious secondary pollutant in many areas, including the Sacramento Valley (SV) of California. The maximum daily 8-h average (MDA8) O_3 in the SV exceeded the 8-h National Ambient Air Quality Standard (NAAQS) of 75 ppbv and the California 8-h standard of 70 ppbv on 45 and 65 days, respectively, during 2009. The total number of exceedance days would have been 85 if the NAAQS were lowered to 65 ppbv as is now being considered by EPA. The NAAQS is designed to provide a margin of safety between background levels of O_3 and those concentrations above which exposure becomes harmful to public health or welfare. The EPA defines Policy Relevant Background (PRB) O_3 concentrations as those that would exist in the absence of anthropogenic emissions from the U.S., Canada, and Mexico. The PRB thus includes O_3 transported across the Pacific from Asia in addition to that produced by photochemical reactions of NO_x, VOCs, and carbon monoxide (CO) emitted from biogenic sources and wildfires, formed by lightning, and introduced into the troposphere from the stratosphere. The adoption of more stringent standards will increase the need to better understand the processes that influence the PRB and to quantify the contribution of background O_3 to ambient concentrations in non-attainment areas.

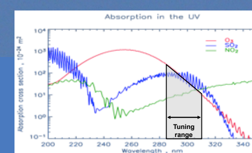
There is ample evidence that long-range transport (LRT) of pollution across the North Pacific Ocean from Asia contributes to surface O_3 in the western U.S.. Numerous studies (e.g. Jaffe, 1999) have examined the contribution of LRT to changes in surface O_3 along the west coast, and a recent study by Cooper et al. (2010) showed that O_3 is also increasing in the free troposphere above the western U.S.. Parrish et al. (2010) recently combined surface O_3 measurements with the Eureka ozonesonde record to assess the impact of LRT on background O_3 levels in California's Northern Sacramento Valley (NSV). They inferred that transport from Asia followed by downward mixing from the lower free troposphere over the NSV contributed ~11 ppbv of the MDA8 O_3 on exceedance days during summer. This represents a substantial fraction of the total MDA8 O_3 and could mean the difference between whether or not an exceedance occurred. This contribution will become even more significant if the NAAQS is reduced to 65 ppbv.

The detection and characterization of LRT layers was a major goal of the TOPAZ airborne O_3 differential absorption lidar (Plate 1) deployment during CalNex. In this study, we describe measurements of the O_3 distribution in the lower free troposphere and boundary layer over the NSV during one such event on 22 June 2010. We show evidence for LRT of O_3 on this day and compare the free tropospheric TOPAZ O_3 measurements with those made at the surface.

Plate 1: Nadir-looking TOPAZ Ozone DIAL aboard the NOAA Twin Otter

Tunable UV laser (3λ, 285 – 310 nm)

- Ozone & aerosol backscatter profiles
- Altitude coverage: ~0.3 to ~3.5 km
- Resolution: H = 10 s or ~650 m
  V = 90 m (O_3), 15 m (aer)
- Precision: 3 – 15 ppbv



TOPAZ Measurements

The Twin Otter flew 16 missions from Sacramento on 10 days over the 14 day period from 15 to 29 June 2010. Flight altitudes ranged from ~2 to 5 km above mean sea level (ASL). Layers with high O_3 of suspected Asian origin were detected over the Sacramento Valley on several days, most notably on 22 June, which we describe here.

Flight of 22 June

Figure 1 (right): The FLEXPART particle dispersion model predicted that a major Asian transport layer would arrive over north-central California near ~ 4 km ASL on the afternoon of 22 June. The model also predicted that there would be no significant inputs from the stratosphere or North American anthropogenic or biomass burning sources in the area.

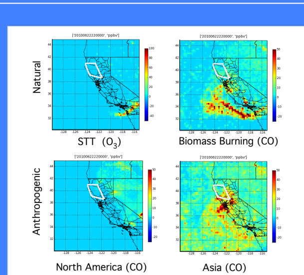


Figure 1

Figure 2 (left) shows the flight plan developed to intercept and map the layer, flying from Sacramento to the coast and then northward to Eureka. The Twin Otter then flew east over the Coastal Range to Redding and from there returned to Sacramento above the NSV. The NASA B200 flew along the same track at a higher altitude, but was obstructed by mid-level clouds.

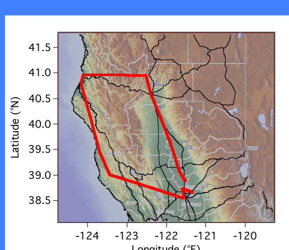


Figure 2

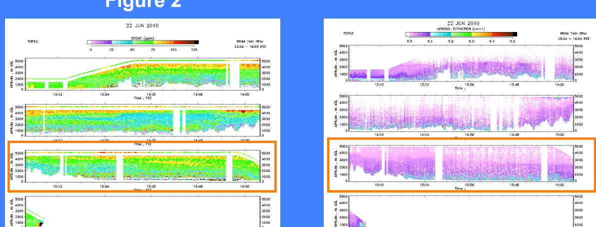


Figure 3

Figure 3 shows time-height curtain plots of O_3 mixing ratios and UV aerosol extinction along the flight track. The gaps correspond to turns when no data were taken. The thin strip at the top of the left panel shows the O_3 measurements from the in-situ monitor aboard the Twin Otter. A layer of high O_3 (90-100 ppbv) extends across the entire flight path near 4 km ASL with the highest concentrations over the Coastal Range (~1500 PST). The right panel shows high aerosol up to ~3 km beneath the O_3 layer. The oranges boxes show the flight leg from Redding to Sacramento over the NSV. A layer with >75 ppbv O_3 slopes downward to the south near 1540 PST. But does this layer influence the surface?

Surface Measurements

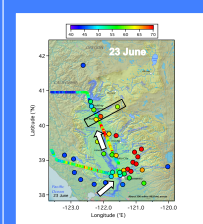


Figure 4

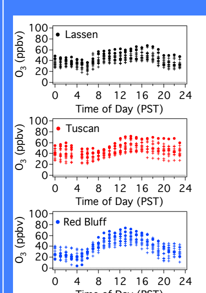


Figure 5

Figure 4 (left) shows the ARB O_3 sampling sites in the NSV (circles). The stations are color-coded to show the MDA8 measured on 23 June. The Twin Otter flight path is color-coded to show the mean O_3 mixing ratio near 3 km ASL on the afternoon of 22 June. Several of the surface stations measured unusually high O_3 on the day after the transport layer appeared overhead. The box encloses the stations at Red Bluff, Tuscan Buttes, and Lassen NP (left to right). Figure 5 (lower left) shows that these stations measured high O_3 during the two nights (circles) following the appearance of the transport layer. Figure 6 (upper right) shows that the high O_3 extended up to at least 1760 m ASL, the elevation of Lassen NP.

The arrows in Figure 4 show the mean late afternoon wind directions from the Chico (CCO) and Sacramento (SAC) profilers (Figure 7 (lower right)). Both profilers show the afternoon CBL to be too shallow (~1100 and ~500 m AGL in SAC and CCO, respectively) to interact with the transport layer. However, SAC shows easterly winds near the surface and a deep (>3 km) nocturnal southerly jet that becomes turbulent further up the valley at CCO. This could have mixed O_3 from the transport layer down to the surface.

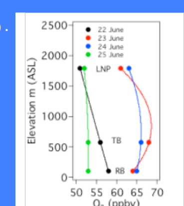


Figure 6

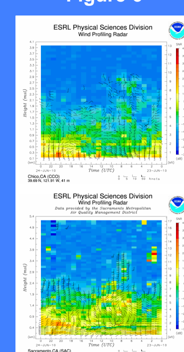


Figure 7

References

Cooper, O. R., et al. (2010), Increasing springtime ozone mixing ratios in the free troposphere over western North America, Nature, 463(7279), 344-348.

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